

# WEATHER EXTREMES IN CALIFORNIA'S VARYING AND CHANGING CLIMATE

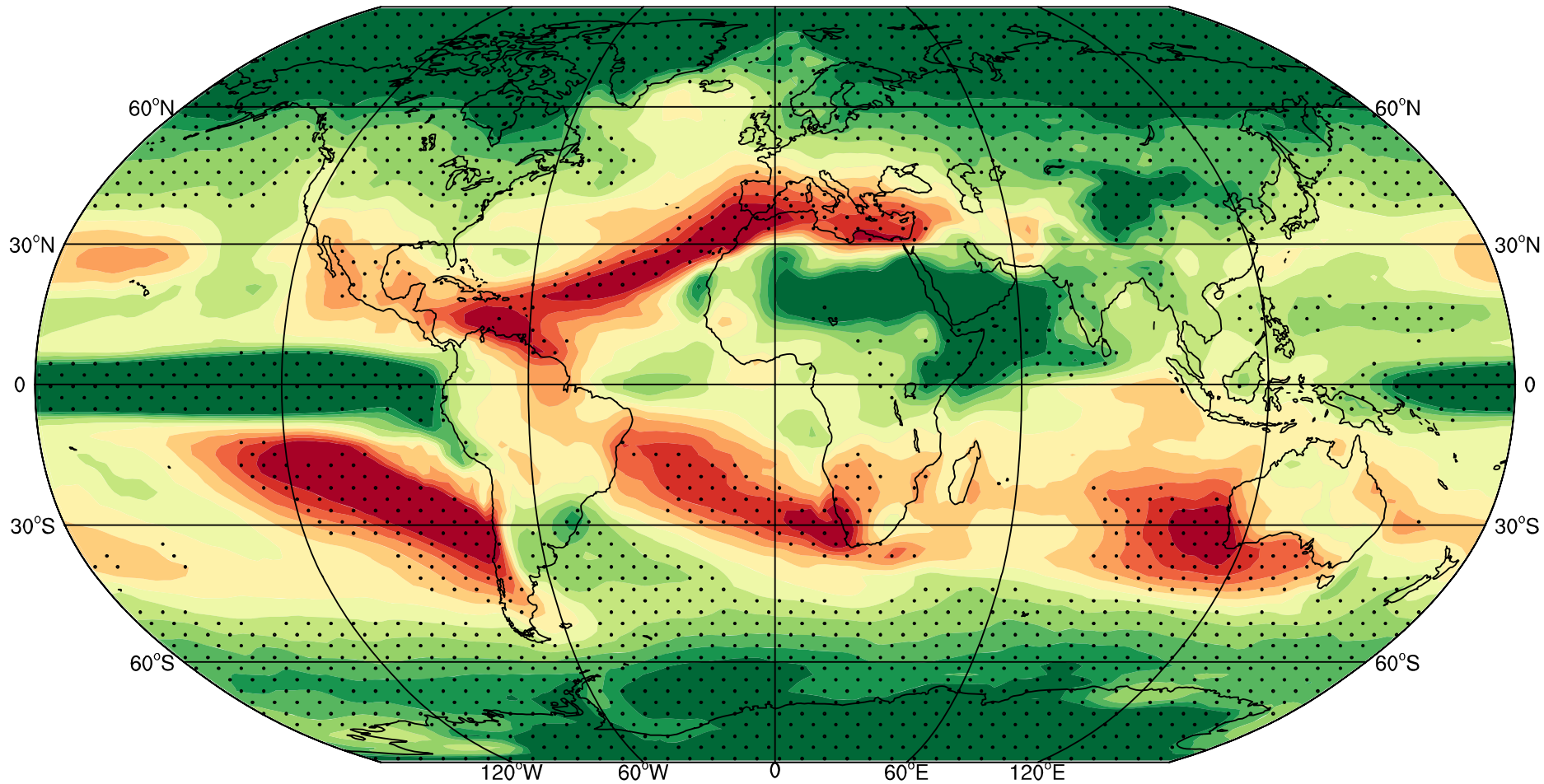
Alexander (Sasha) Gershunov, Kristen Guirguis,  
Rachel Clemesha, Tamara Shulgina,  
Janin Guzman Morales

Dan Cayan, Michael Dettinger,  
Marty Ralph, David Pierce



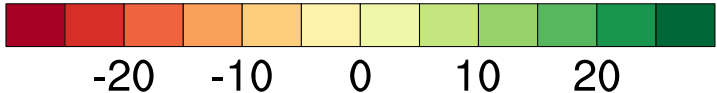
*Sponsors:*  
California Dept Water Resources  
California Energy Commission  
NOAA RISA program "CNAP"  
Bureau of Reclamation  
Southwest Climate Science Center

# Precipitation Regime Change



(%)

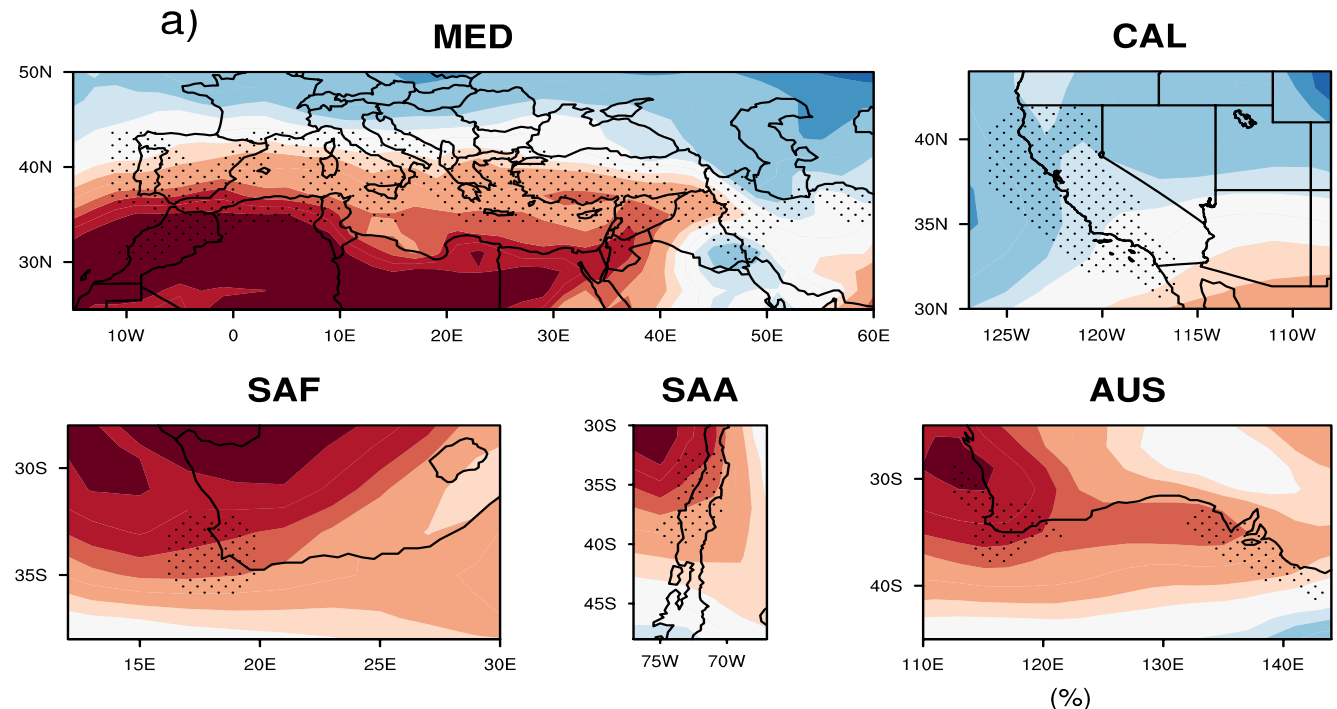
Polade, S.D., D.W. Pierce, D.R. Cayan, A. Gershunov and M.D. Dettinger, 2014: The key role of dry days in changing regional climate and precipitation regimes. *Nature Scientific Reports* 4, 4364; DOI:10.1038/srep04364.



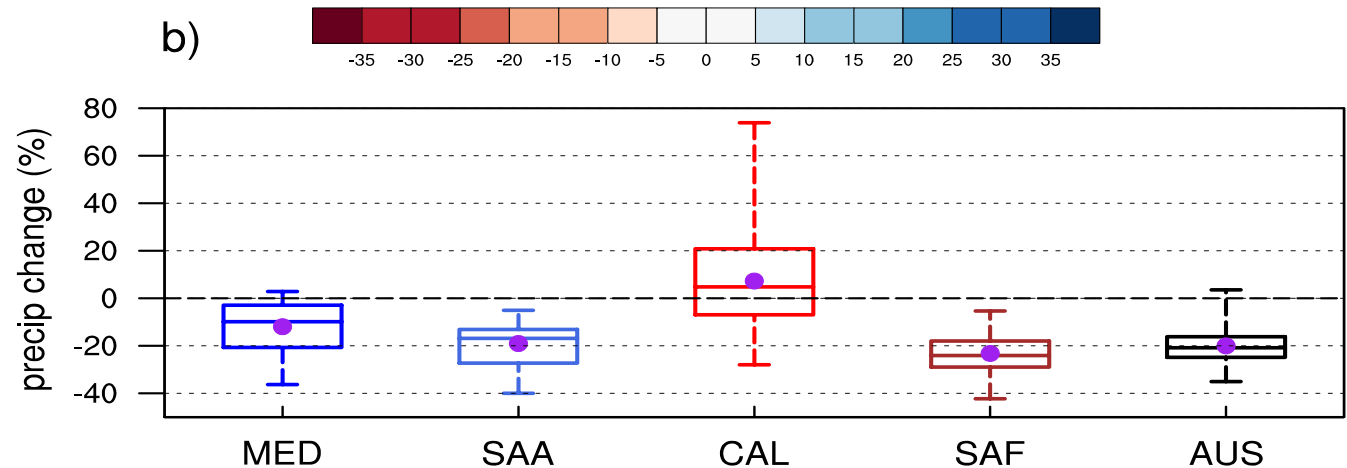
# Precipitation Regime Change

In Mediterranean Climate Regions

WINTER  
DJF



b)

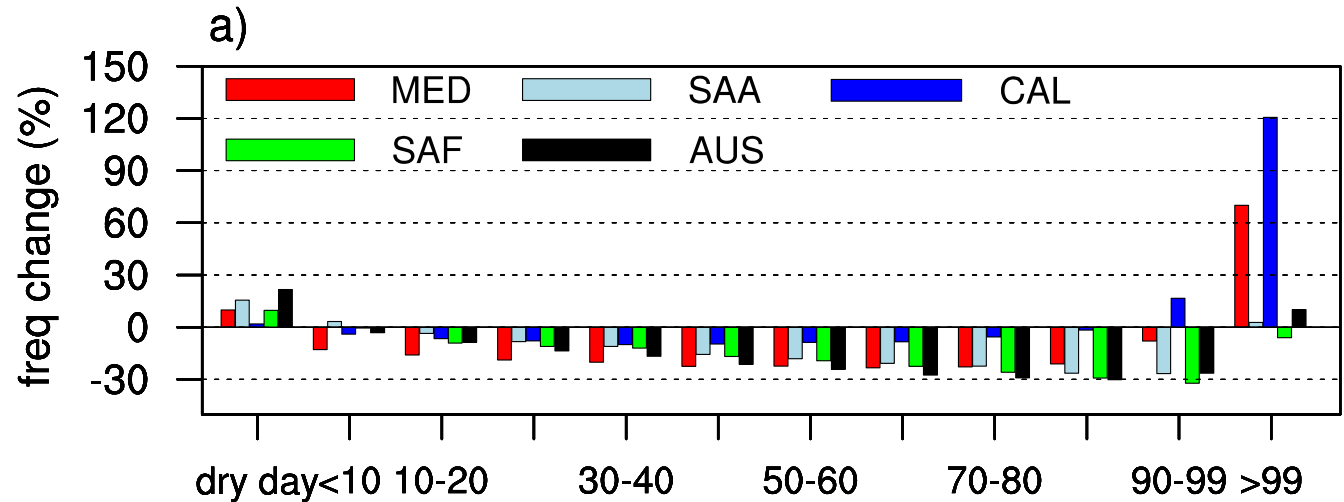


Polade, S.D., A. Gershunov,  
D. Cayan, M.D. Dettinger  
and D.W. Pierce, 2017:  
Precipitation in a warming  
world: Assessing projected  
hydro-climate of California  
and other Mediterranean  
climate regions. *Nature  
Scientific Reports*, 7:

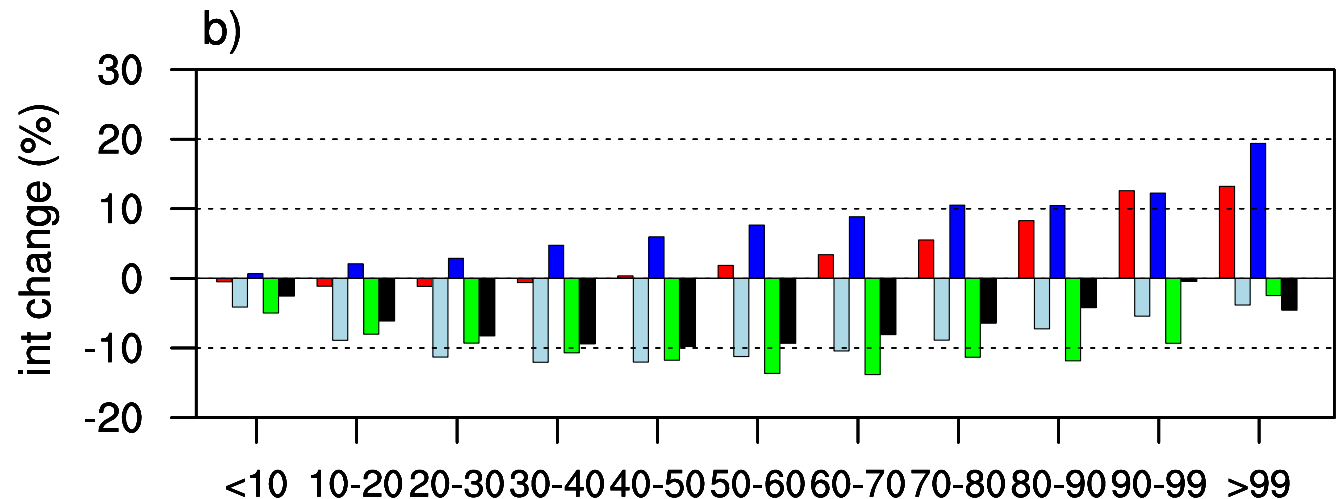
10783,  
DOI:10.1038/s41598-017-  
11225

# Precipitation Regime Change

In Mediterranean Climate Regions

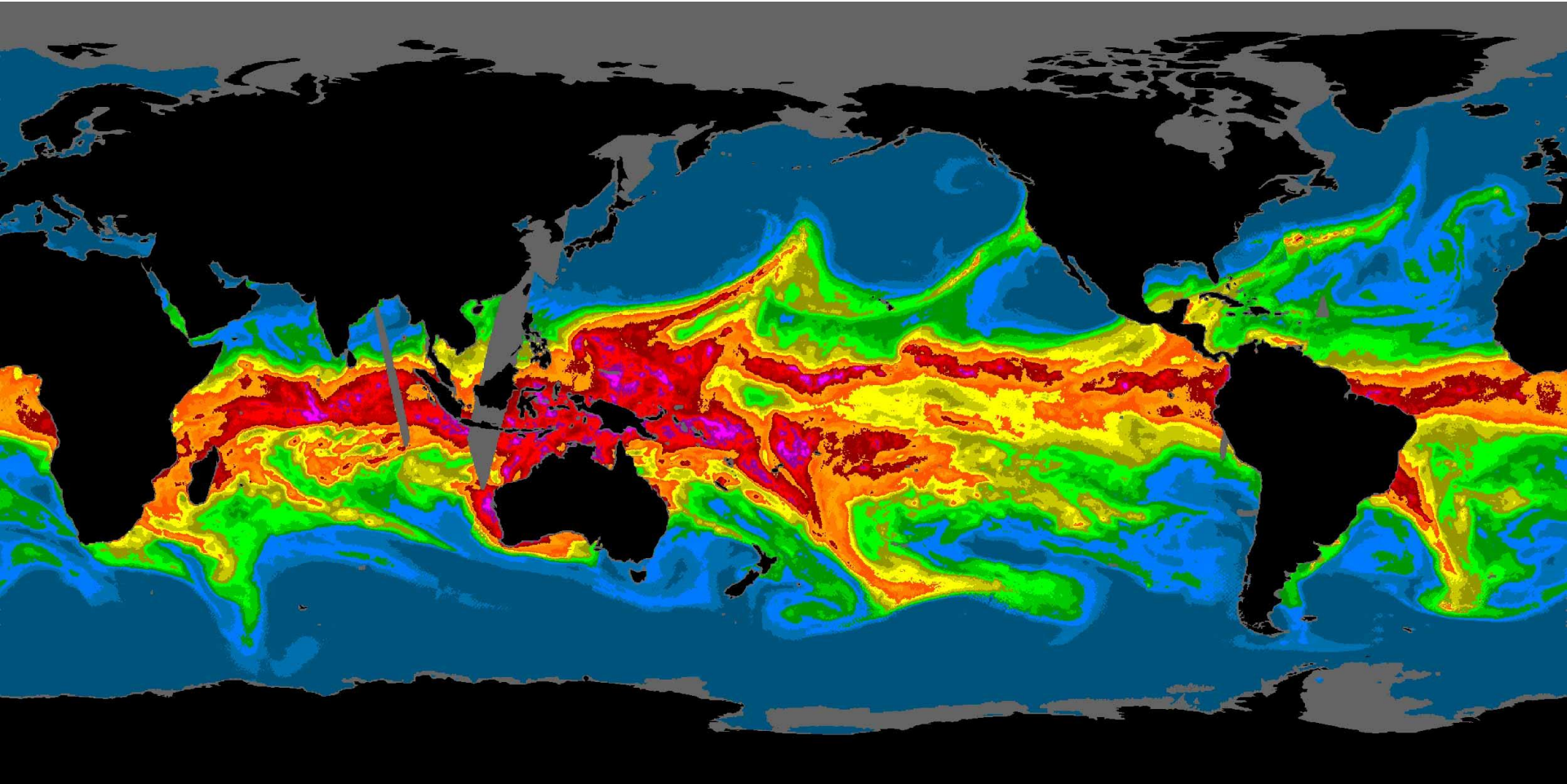


DAILY PRECIPITATION INTENSITY BINS





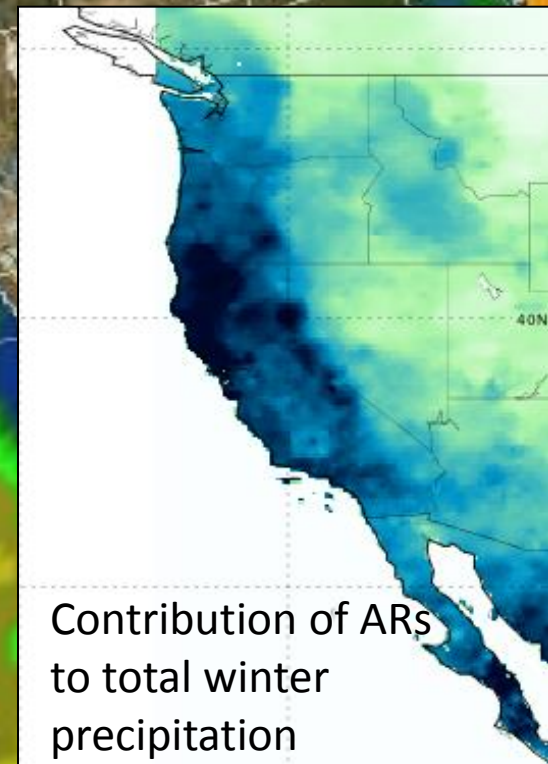
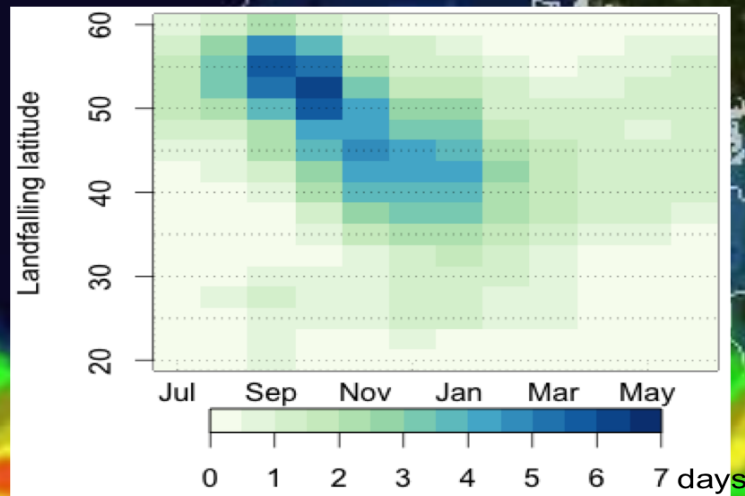
# Atmospheric Rivers



Gershunov A., T.M. Shulgina, F.M. Ralph, D. Lavers and J.J. Rutz, 2017:  
Assessing climate-scale variability of Atmospheric Rivers affecting  
western North America. *Geophysical Research Letters*, 44,  
doi:10.1002/2017GL074175.

# Atmospheric Rivers

## Climatology of Atmospheric River Landfalls



Gershunov A., T.M. Shulgina, F.M. Ralph, D. Lavers and J.J. Rutz, 2017: Assessing climate-scale variability of Atmospheric Rivers affecting western North America. *Geophysical Research Letters*, 44, doi:10.1002/2017GL074175.



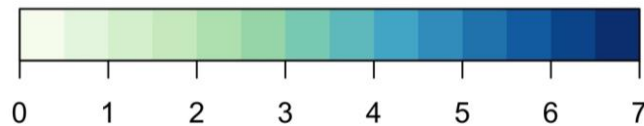
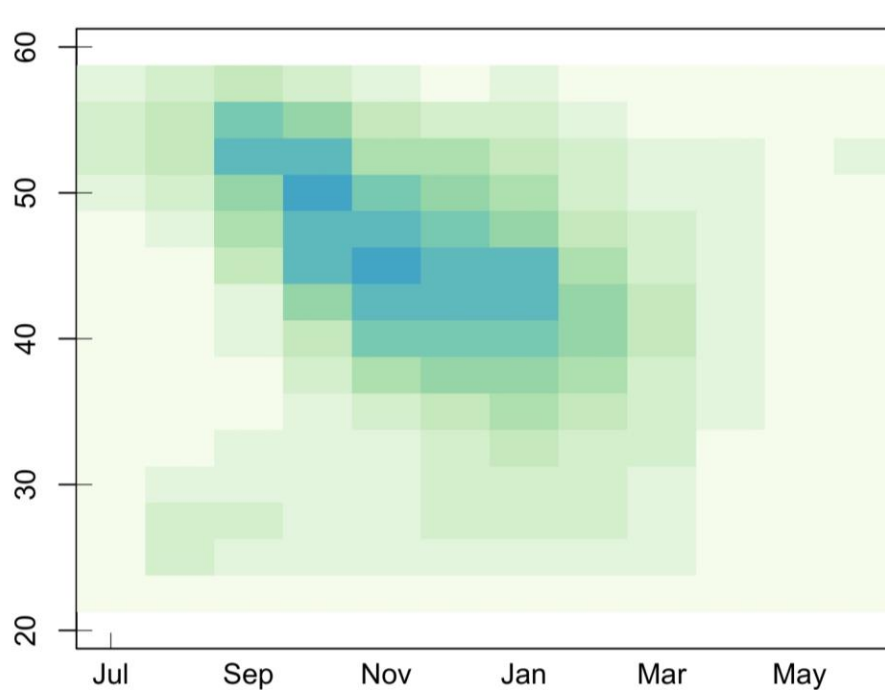
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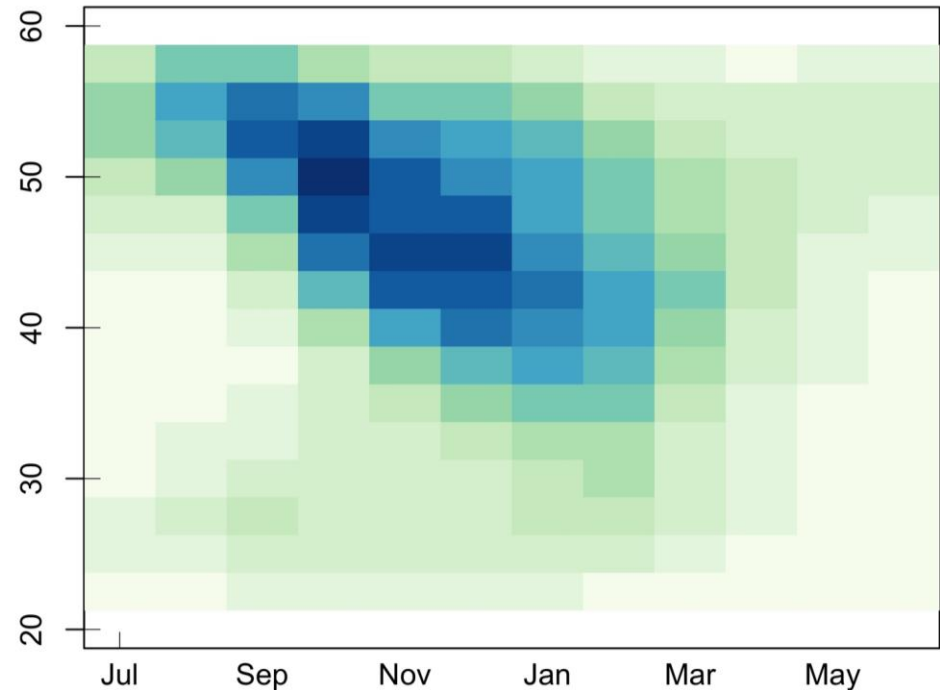


# Atmospheric Rivers

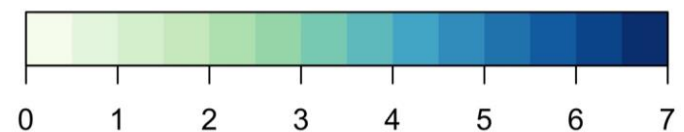
HISTORICAL LANDFALL FREQUENCY



END OF CENTURY LANDFALL FREQUENCY



DAYS



1970-1999

ENSEMBLE OF 15 GCMs

2070-2099

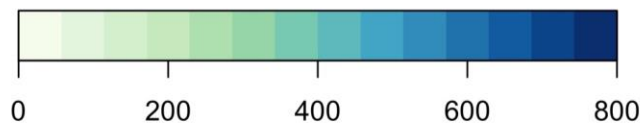
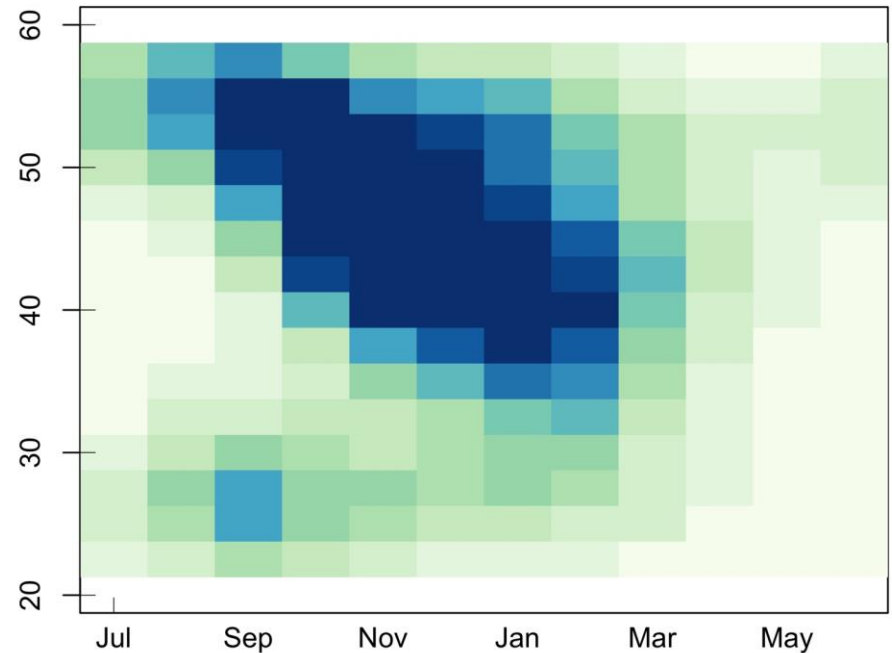
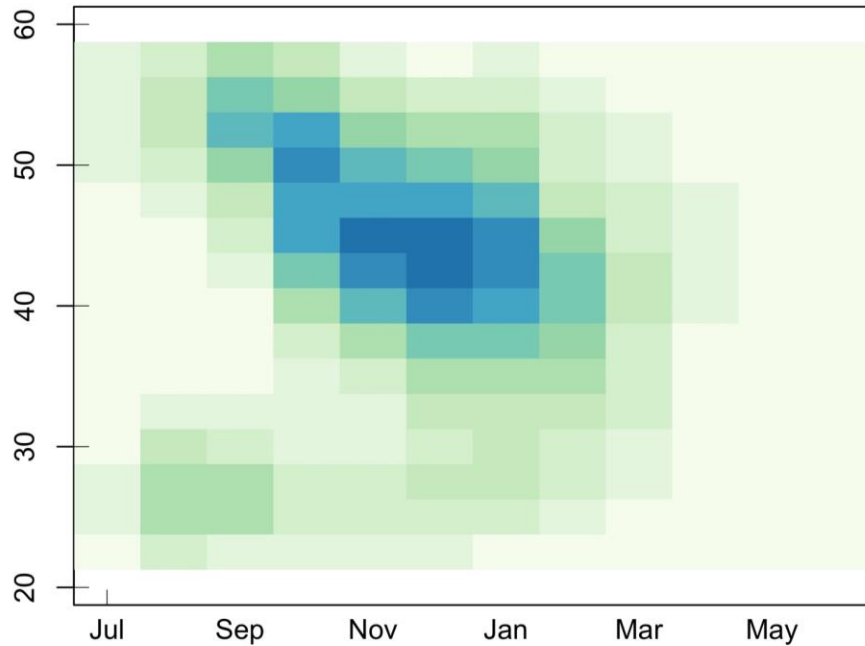


Integrated Water Vapor (cm) Nov 30, 2012 15 UTC

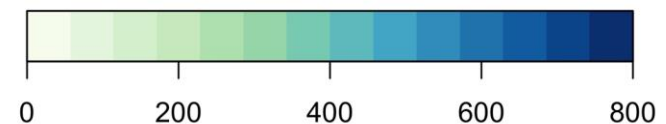
# Atmospheric Rivers

HISTORICAL LANDFALL INTENSITY

END OF CENTURY LANDFALL INTENSITY



IVT > 250  
kg/m/s



1970-1999

ENSEMBLE OF 15 GCMs

2070-2099

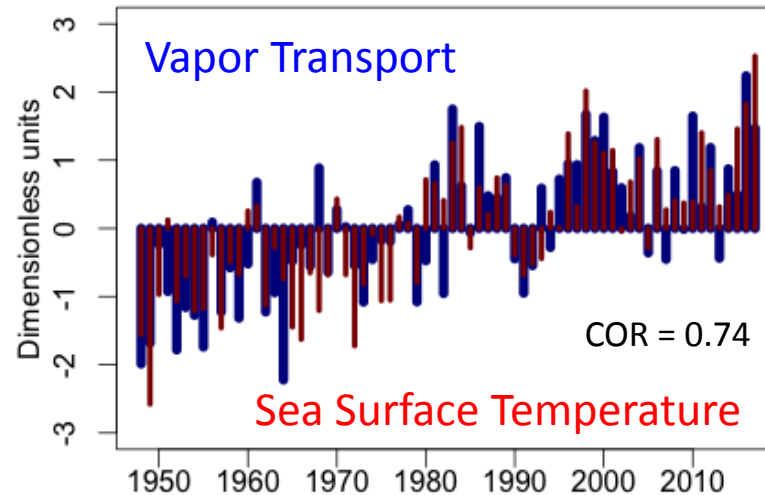


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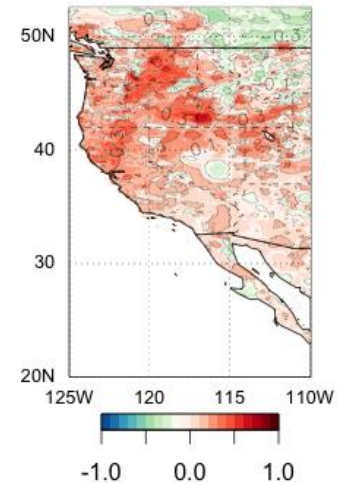


# Atmospheric Rivers

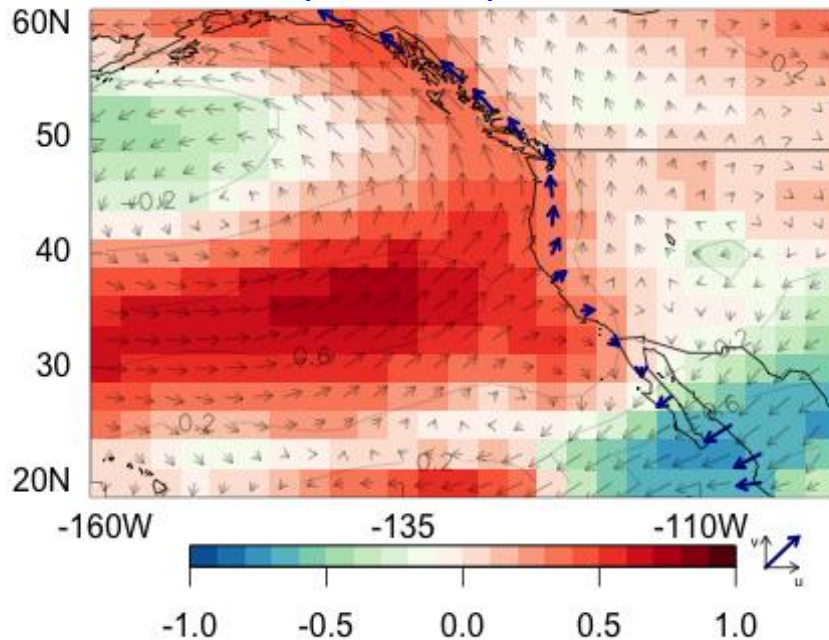
CANONICAL  
CORRELATION  
ANALYSIS (CCA)  
SECOND COUPLED MODE  
OF VAPOR TRANSPORT  
AND SST  
(JFM)



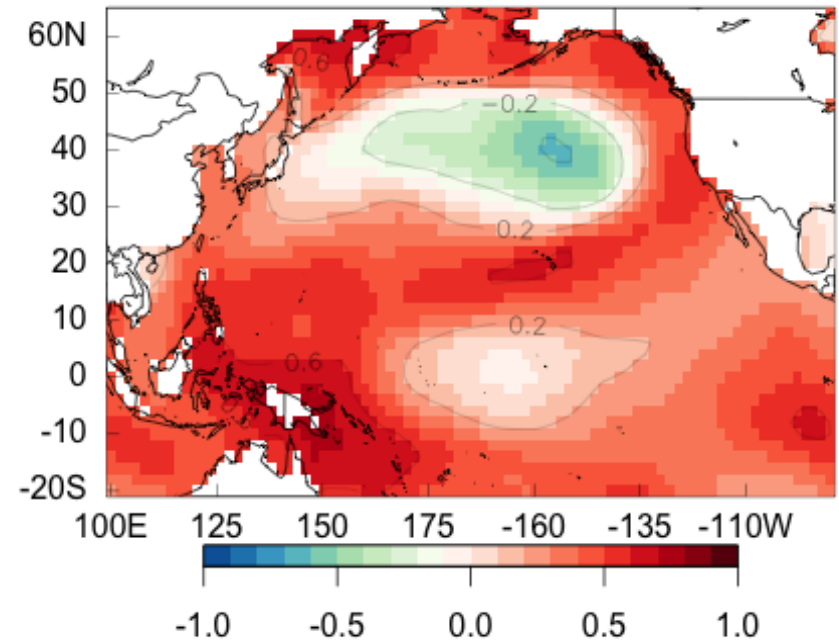
Precipitation



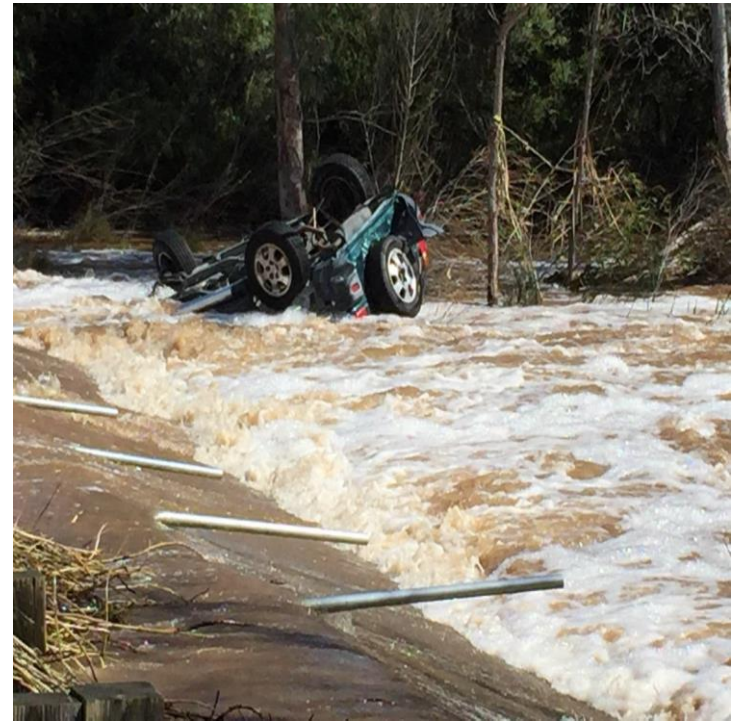
Vapor Transport



Sea Surface Temperatures



# Heavy Rainfall and Historic Flooding in San Diego - February 27-28, 2017 towards the end of a historic drought





# Weather Extremes in a Varying and Changing Climate

## Precipitation Regimes and Extremes

- Precipitation is projected to become less frequent, especially in shoulder seasons
- But extremes get more extreme
- Year-to-year variability increases
- More volatility in water resources



# Weather Extremes in a Varying and Changing Climate

Precipitation Regimes and Extremes

Heat Waves and Cold Spells

Marine Layer Clouds

Santa Ana Winds

Atmospheric Rivers

Droughts and Floods



# Heat Waves

- Sherbakov, T., B.J. Malig, K. Guirguis, A. Gershunov, R. Basu, 2017: Ambient Temperature and Added Heat Wave Effects on Hospitalizations in California from 1999-2009. *Environmental Research*, in press.
- Clemesha, R.E.S., K. Guirguis, A. Gershunov, I. Small and A.Tardy, 2017: California heat waves: their spatial evolution, variation and coastal modulation by low clouds. *Climate Dynamics*, in press.
- Guirguis, K., A. Gershunov, D.R. Cayan and D. Pierce, 2017: Heat wave probability in the changing climate of the Southwest US. *Climate Dynamics*, doi: DOI 10.1007/s00382-017-3850-3.
- Guirguis, K., A. Gershunov and D. Cayan, 2015: Interannual variability in associations between seasonal climate, weather and extremes: wintertime temperature over the Southwestern United States. *Environmental Research Letters*, 10, 124023, doi:10.1088/1748-9326/10/12/124023.
- Guirguis, K., A. Gershunov, A. Tardy and R. Basu, 2014: The Impact of Recent Heat Waves on Human Health in California. *Journal of Applied Meteorology and Climatology*, 53, 3-19.
- Gershunov A. and K. Guirguis, 2012: California heat waves in the present and future. *Geophysical Research Letters*, 39, L18710, doi:10.1029/2012GL052979.
- Gershunov, A, Z. Johnston, H.G. Margolis and K. Guirguis, 2011: The California Heat Wave 2006 with Impacts on Statewide Medical Emergency: A space-time analysis. *Geography Research Forum*, 31, 6-31.
- Gershunov, A., D. Cayan and S. Iacobellis, 2009: The great 2006 heat wave over California and Nevada: Signal of an increasing trend. *Journal of Climate*, 22, 6181-6203.



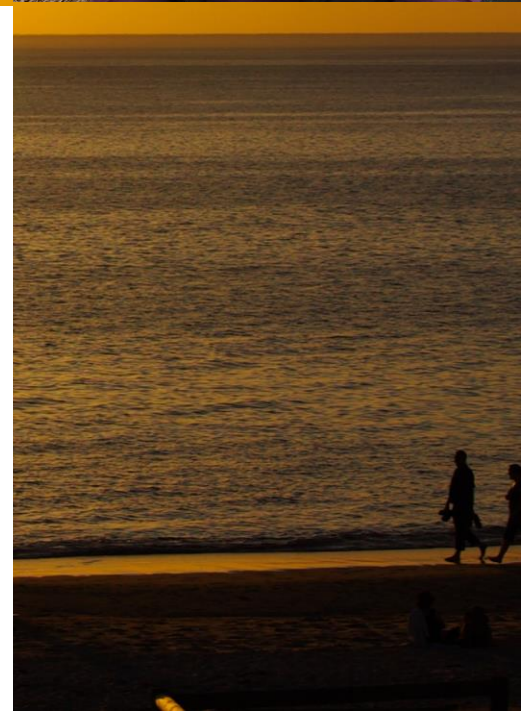
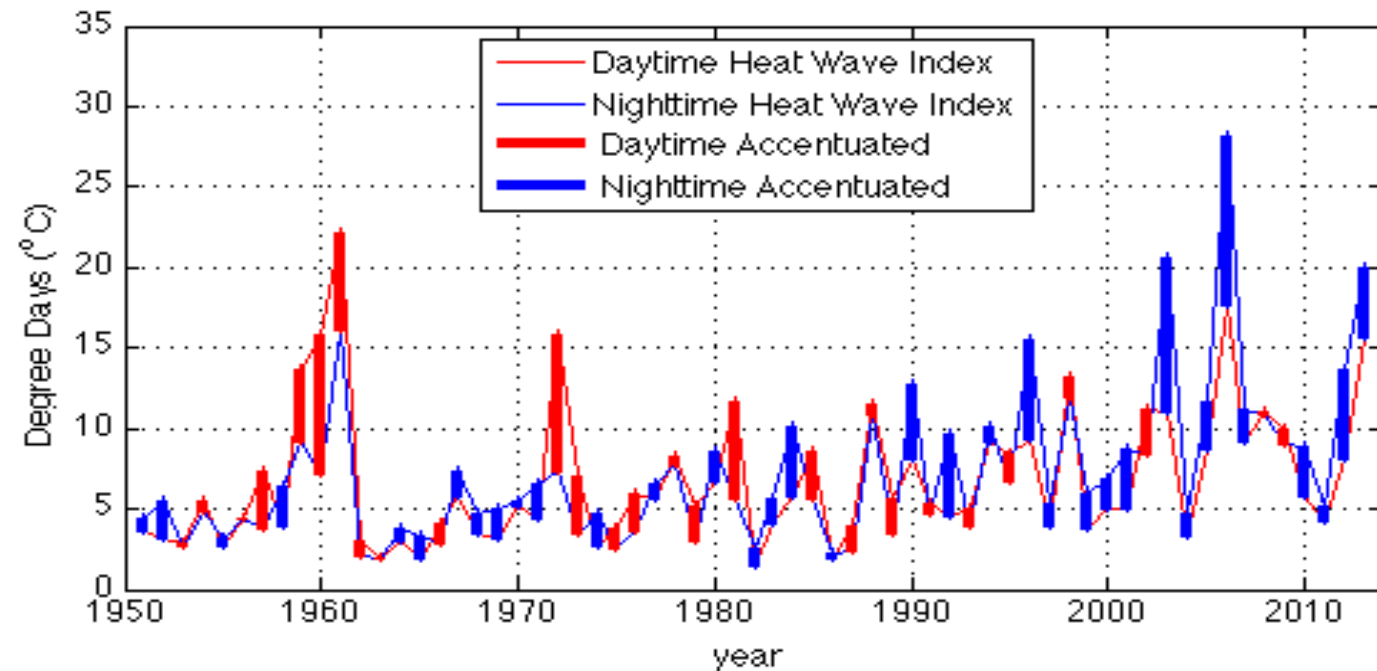


# Heat Waves

## HUMID HEAT WAVES ARE ON THE RISE

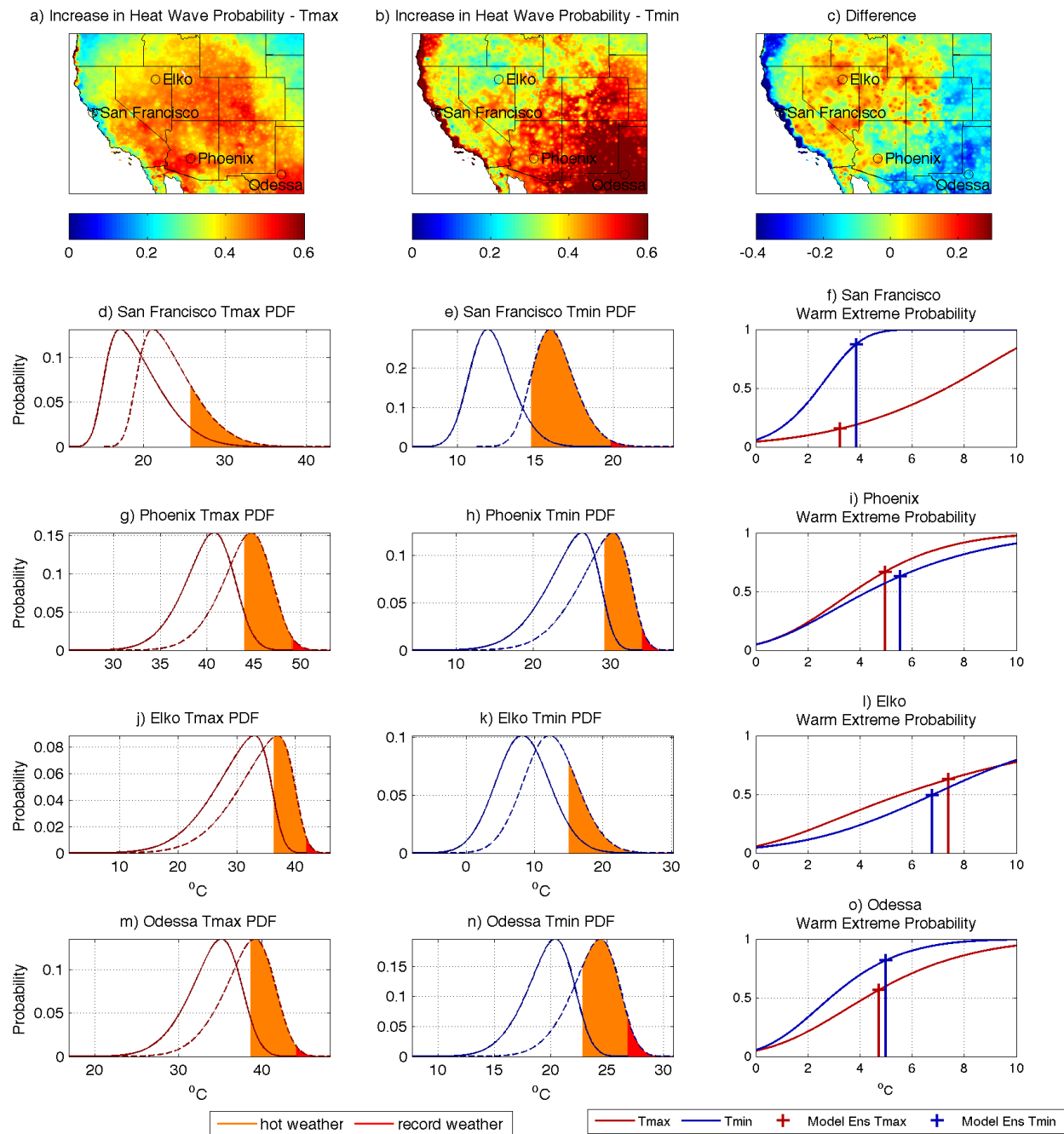
Observed Heat wave index for California

With Kristen Guirguis





# Future Heat Wave Probability Depends on the Local Climatology



# Heat Waves



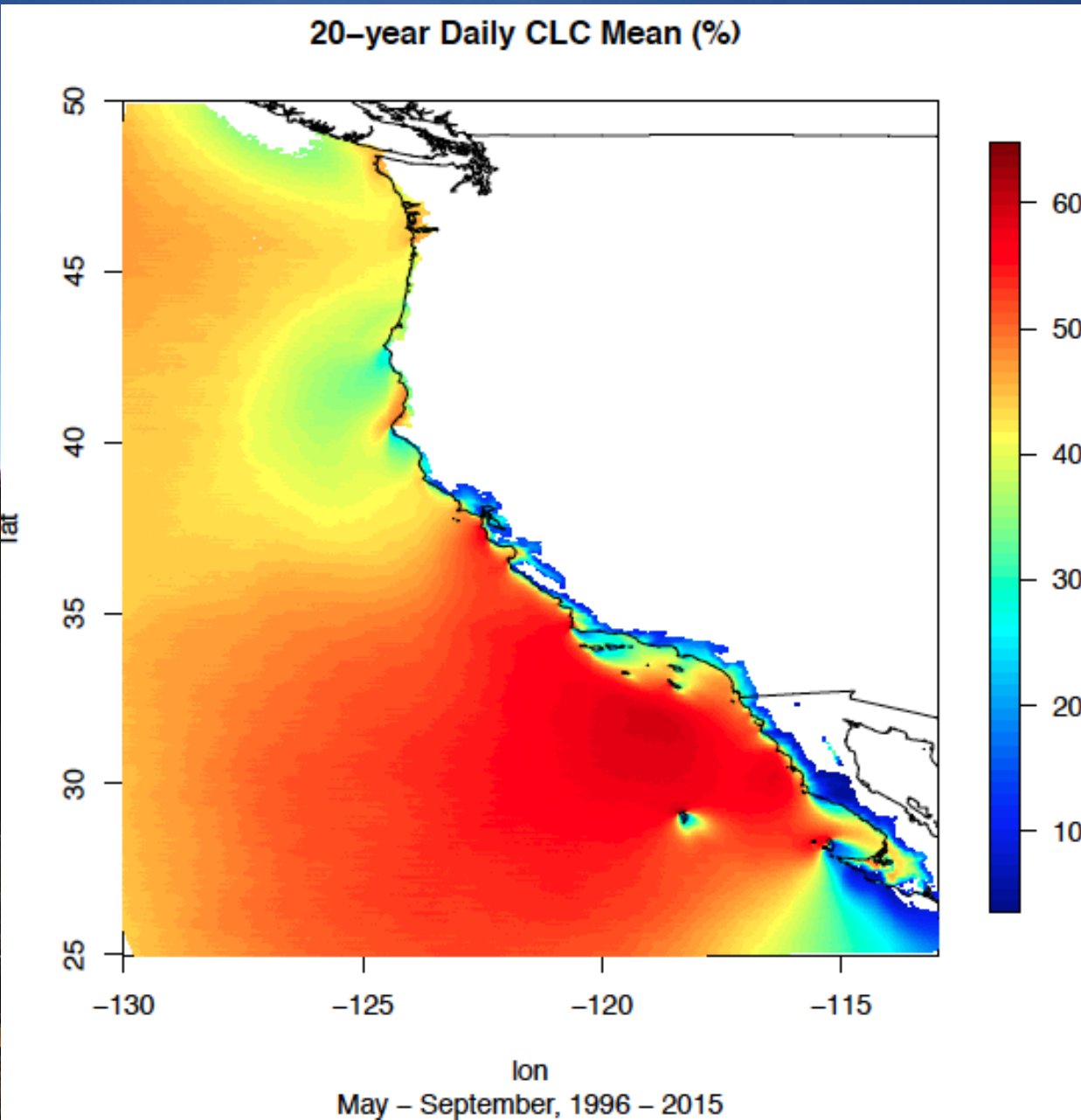
**National Weather Service**

National Oceanic and Atmospheric Administration

**EXPERIMENTAL NWS POTENTIAL HEAT RISKS**

<http://www.wrh.noaa.gov/wrh/hil/?id=1yHbjQJfR8TAqBMvK-bA6uR3MEYv0R69VaFIWFL8dcq8&wfo=SGX>

# Marine Layer Clouds



With Rachel Clemesha

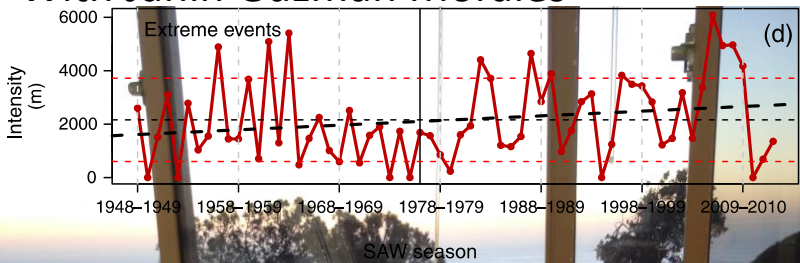
: California heat waves:  
s. *Climate Dynamics*, in  
Daily Variability of California  
ence. *Geophysical*

ams, 2016: The Northward  
*Physical Research Letters*, 43.  
North American West Coast  
Surface Temperature.  
59825



# Santa Ana Winds

With Janin Guzman Morales

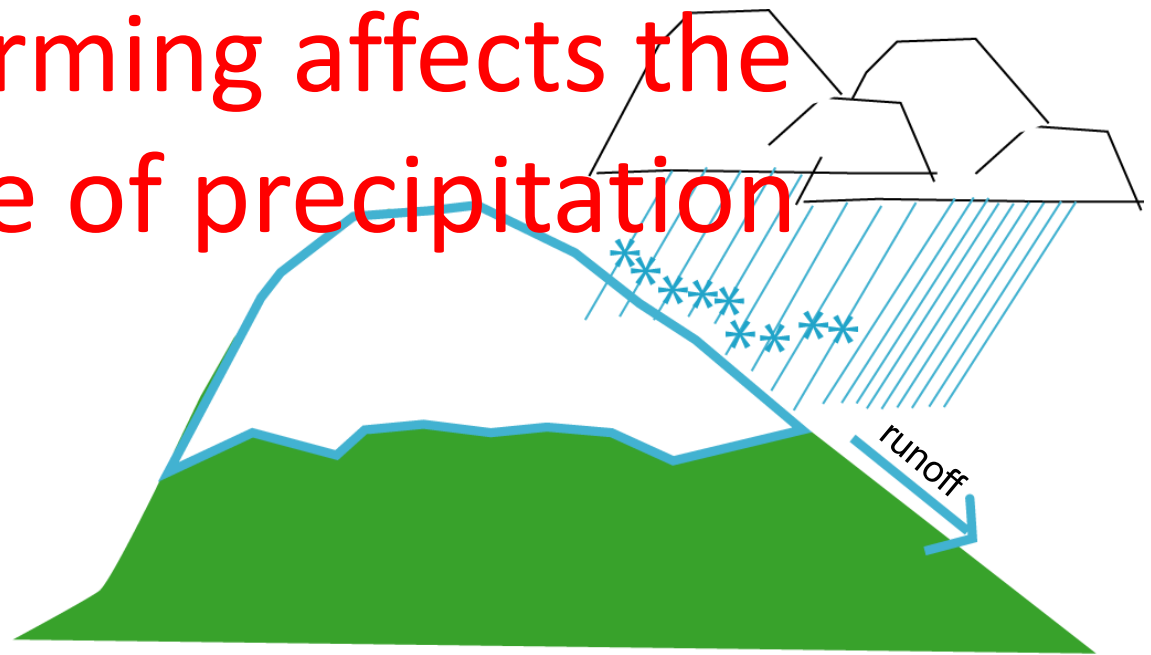


Guzman Morales, J., A. Gershunov, J. Theiss, H. Li and D. Cayan, 2016: Santa Ana Winds of southern California: their climatology, extremes and behavior since 1948. *Geophysical Research Letters*, 43, doi:[10.1002/2016GL067887](https://doi.org/10.1002/2016GL067887).

# Warming affects the type of precipitation

*historically:*

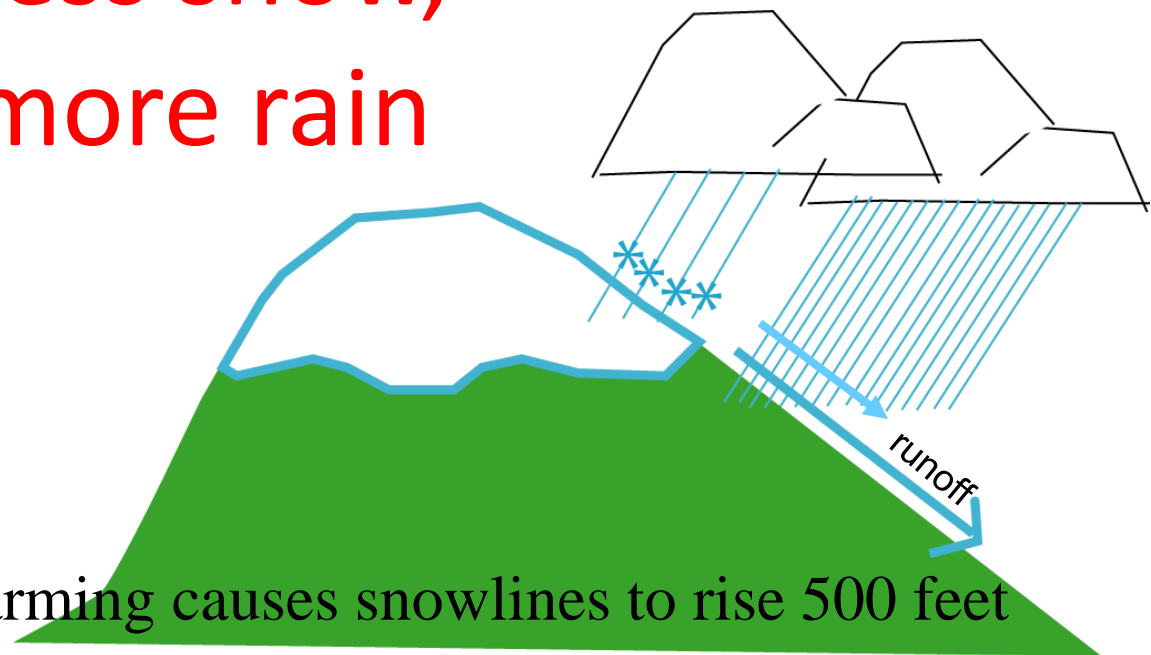
“Cool” storms contribute immediate runoff from smaller areas of the river basin (the rest goes into snowpack for later)



## Less snow, more rain

*In a warmer climate:*

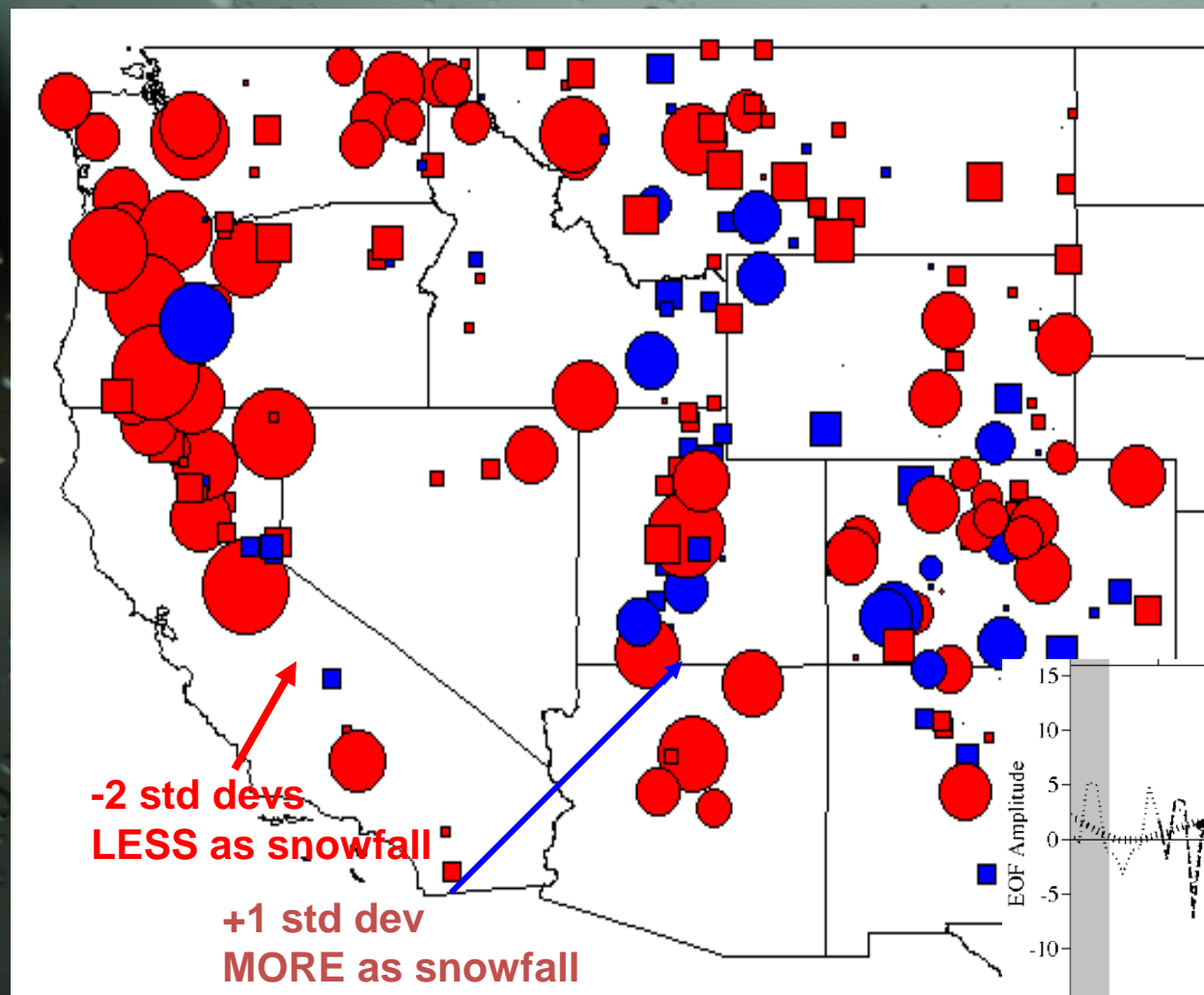
Warm storms contribute immediate runoff from larger areas of the river basin



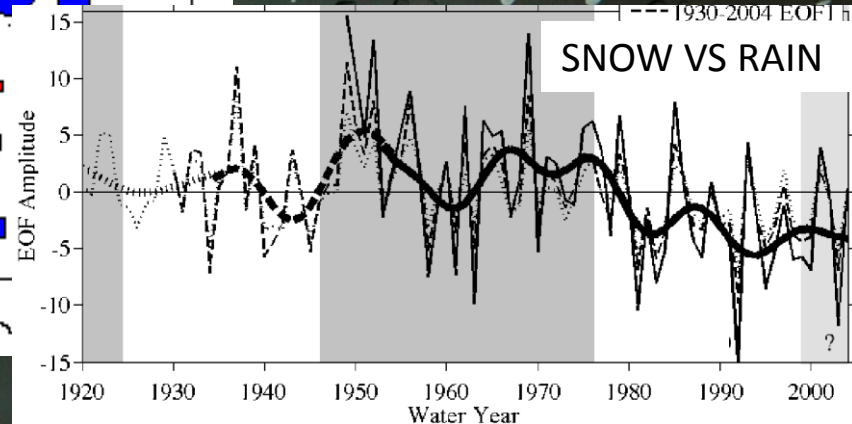
1° C (1.8 ° F) warming causes snowlines to rise 500 feet



*Recent trends:* Observed warming has already driven measurable hydrologic changes.  
**--> Less snow/more rain**

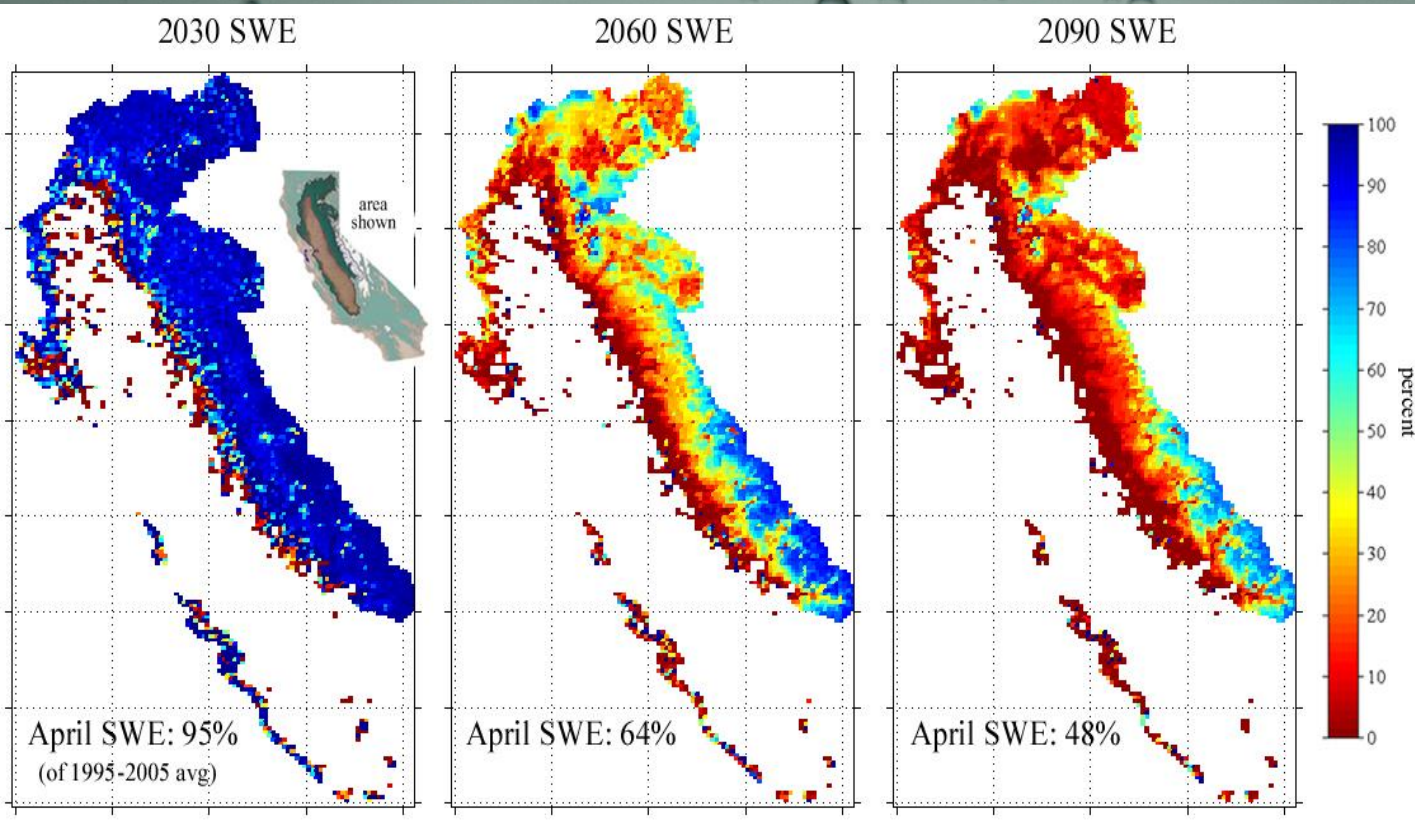


THIS FIGURE SHOWS  
OBSERVED TRENDS  
IN THE RATIO  
BETWEEN SNOW AND  
RAIN: SNOW IS  
DECREASING RELATIVE  
TO RAIN AT MOST  
MOUNTAIN LOCATIONS  
-> AN EXPECTED  
CONSEQUENCE OF  
WARMING





# We face significant losses of spring snowpack



- Less snow, more rain
- Particularly at lower elevations
- Earlier run-off
- More floods
- Less stored water

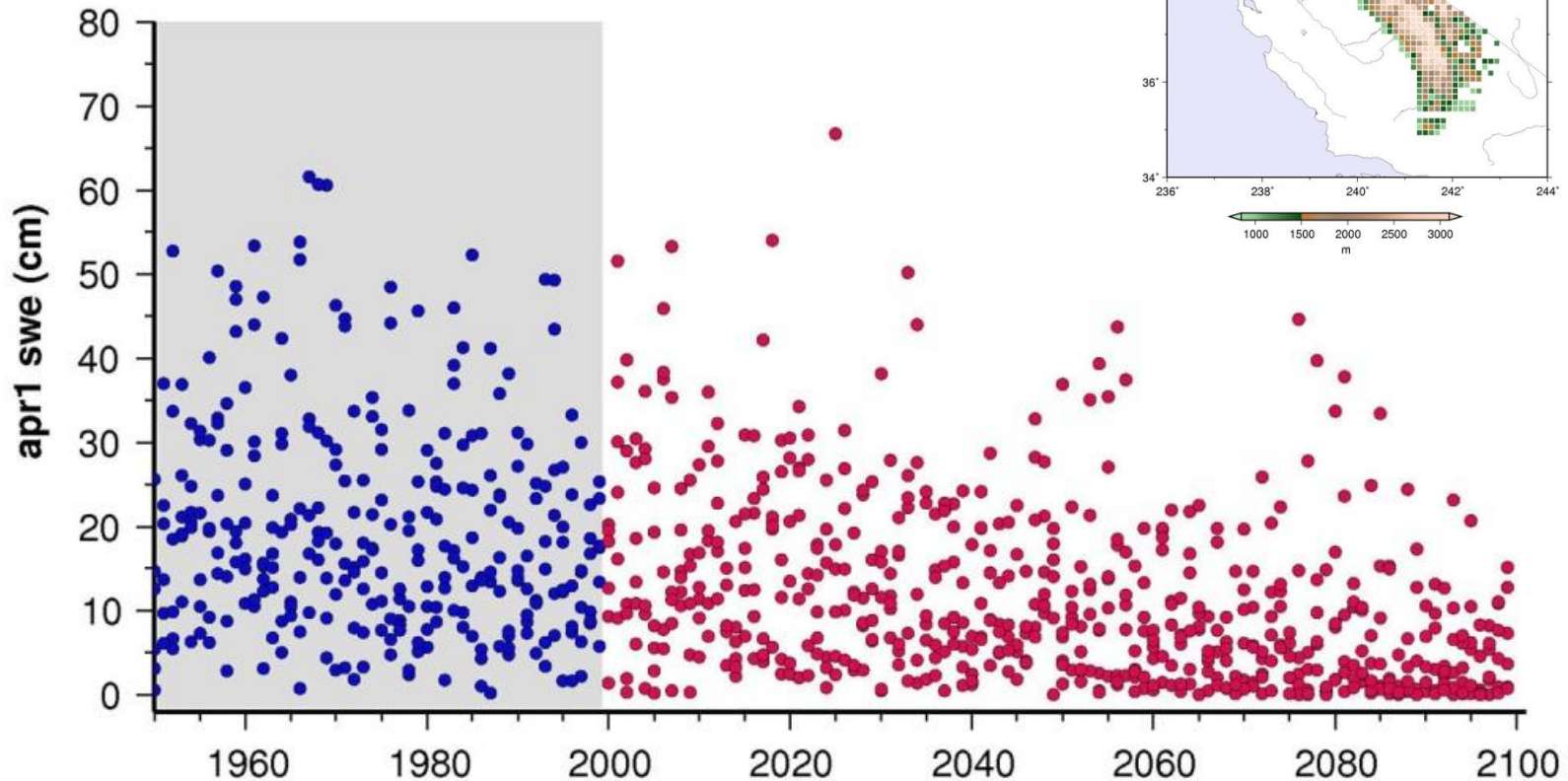
*By the end of the century California could lose half of its late spring snow pack due to climate warming. This simulation by Noah Knowles is guided by temperature changes from PCM's Business-as-usual climate simulation. (a middle of the road emissions scenario)*

# Projected Snow Water Equivalent (SWE)

hi sierra apr 1 swe

BCSD (1950–2099; 6 gcms)

Snow Water Equivalent



**Warming** and drying results in reduced Mountain Snow Pack.  
Cold wet extremes become progressively less frequent,  
while minimal spring SWE – more and more likely.

from VIC simulations of 6 GCMs A2 scenario simulations



# Rising Seas in California

AN UPDATE ON SEA-LEVEL RISE SCIENCE

## OTHER RELEVANT WORK AT SCRIPPS

### CONTRIBUTORS

#### Working Group Members

Gary Griggs *University of California Santa Cruz, OPC-SAT  
Working Group Chair)*

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Claudia Tebaldi *National Center for Atmospheric Research  
& Climate Central*

Helen Amanda Fricker *Scripps Institution of Oceanography*

Joseph Árvai *University of Michigan*

Robert DeConto *University of Massachusetts*

Robert E. Kopp *Rutgers University*

#### Project Team

Liz Whiteman *California Ocean Science Trust*

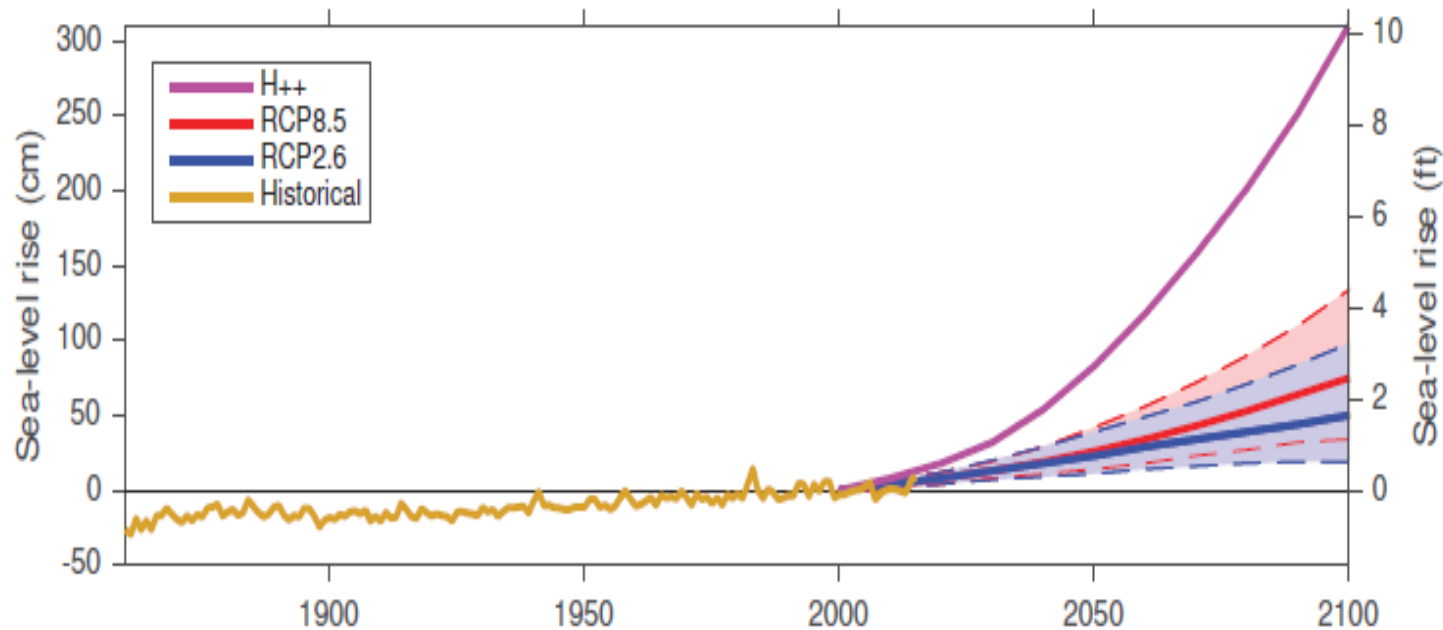
Susi Moser *Susanne Moser Research & Consulting*

Jenn Fox *Consultant*

APRIL 2017

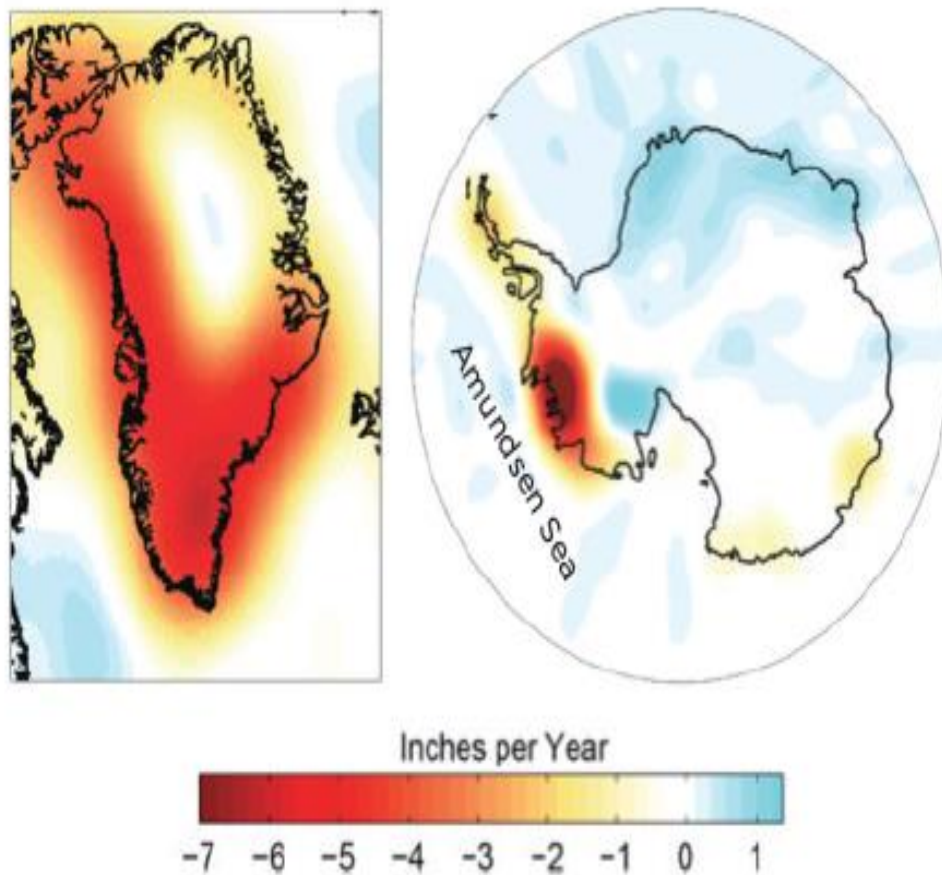


## San Francisco Relative Sea Level



Sea-level rise projections for RCP 8.5 and RCP 2.6 are calculated using the methodology of Kopp et al., 2014. The shaded areas bounded by the dashed lines denote the 5th and 95th percentiles.

The H++ scenario corresponds to the Extreme scenario of Sweet et al. (2017) and represents a world consistent with rapid Antarctic ice sheet mass loss.



Spatial patterns of ice mass loss (inches of water equivalent lost per year between 2003 and 2012) over Greenland and Antarctica (left), inferred from the GRACE (Gravity Recovery and Climate Experiment) satellites' measurements of Earth's gravitational field (Velicogna et al., 2014; Velicogna and Wahr, 2013). Note the widely distributed ice loss around much of the Greenland Ice Sheet margin. In contrast, Antarctica's ice mass loss is concentrated in the Amundsen Sea sector of West Antarctica, where warming sub-surface ocean temperatures are in direct contact with the underside of ice shelves (figure source: NASA Jet Propulsion Laboratory).

If recent trends continue, the contribution from the Greenland and Antarctic ice sheets will soon overtake that from mountain glaciers and ocean thermal expansion as the dominant source of sea-level rise.

The Greenland Ice Sheet (GIS) is currently losing mass at a faster rate than the Antarctic Ice Sheet (AIS), but, *emerging science suggests that ice loss from the Antarctic Ice Sheet poses the greatest potential risk to California coastlines over the next 100 years.*



SEA LEVEL RISE

Other impacts of climate change....

High tide at La Jolla Shores  
Beach and Tennis Club  
December 4, 2013



## SHORTER PERIOD

### THREATS—

during high sea levels, the sea is often *not* quiescent



January 1983 Monterey Bay, California



# SUMMARY OF CLIMATE CHANGE

- CLIMATE IS THE STATISTICS OF WEATHER
- A particular storm or temperature record or any weather event cannot be clearly attributed to climate change, but its probability can be.
- In the same way, a particular home run, performance in a competition or record broken cannot be attributed to an athlete's use of steroids, but the statistics of an athlete's performance over a season can be.
- So, climate change can be thought of as *weather on steroids*.
- This analogy is explored further here <https://www2.ucar.edu/atmosnews/attribution>